Bipolar Model Standardization
Mextram 503.2

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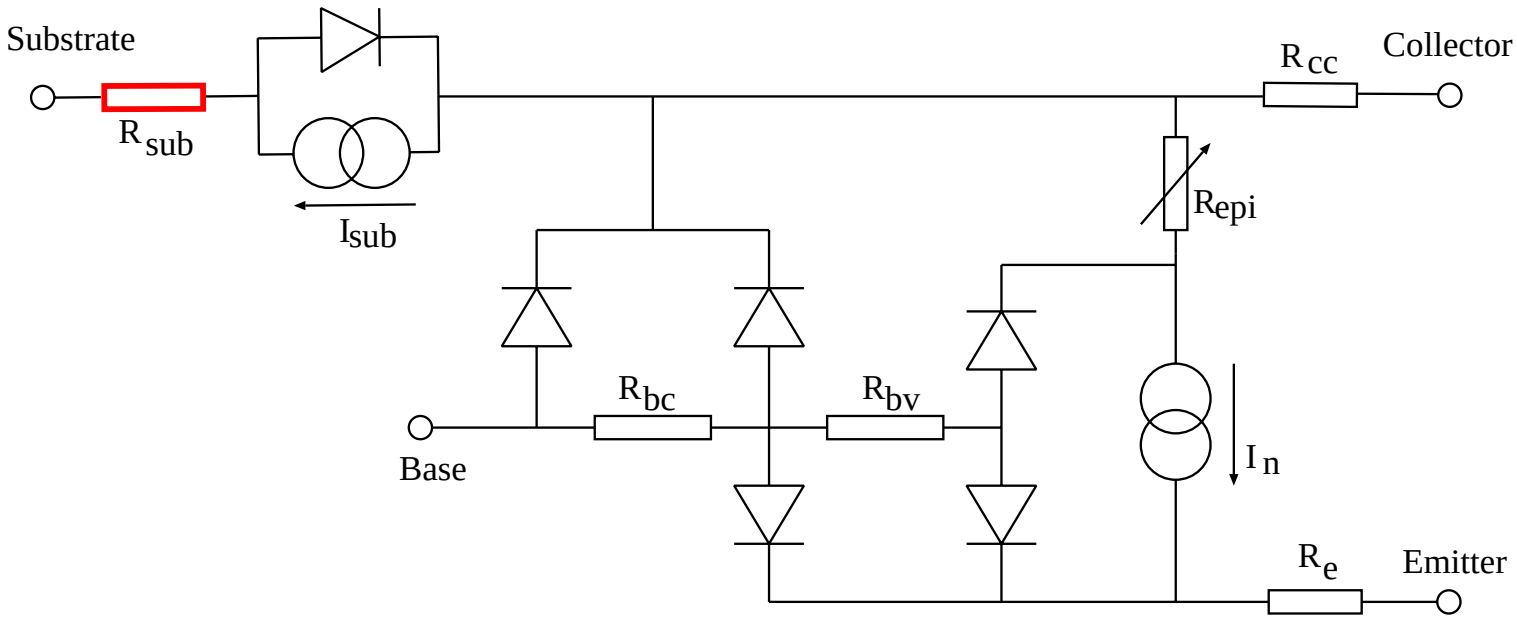
Outline

- Introduction
- Extended Mextram circuit model
- Results
  - process A
    - Mextram 503.2
    - Current and charge at onset of quasi-saturation Mextram 504.0
  - process C
  - process D
  - process E
- Remarks

- bipolar vertical NPN/PNP compact transistor model
- discrete and integrated circuit model
- analog/digital, RF/power applications
- low/high voltage, low/high frequency
- Survey of modelled effects
  - modelling of I_c including high injection, bias dependent Early effect
  - modelling of I_b including non ideal base current
  - charge storage effects
  - explicit modelling inactive regions (parasitic PNP)
  - extensive modelling of the collector region including quasi-saturation, hot carrier effect, avalanche multiplication
  - temperature effect

- noise modelling
- geometric scaling rules are not part of the model
  (in contrast with MOS compact models)
- public domain since 1993
  - **http://www.semiconductors.philips.com/Philips_Models/**
  - documentation
  - source code
- new release in june 2000

Extended Equivalent Circuit Mextram (4)



- substrate resistance R_{sub} (depending on circuitry)
- self-heating is a feature of the in-house circuit simulator

$$T_{dut} = \mathrm{TEMP} + R_{th} \cdot (I_c \cdot V_{ce} + I_b \cdot V_{be})$$

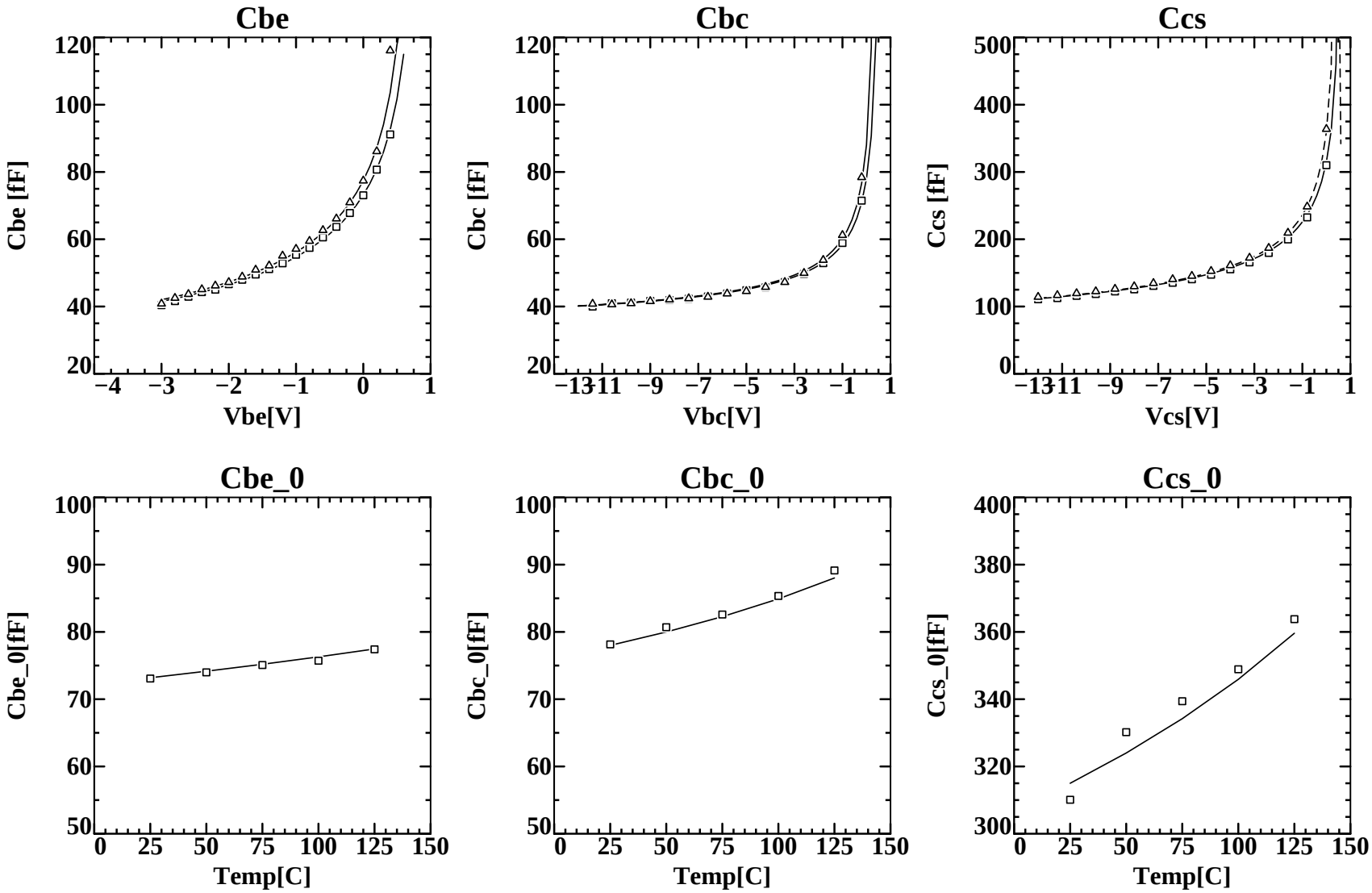
process A: Single Poly BiCMOS process

emitter size: $0.6 \times 5.4 \mu m$

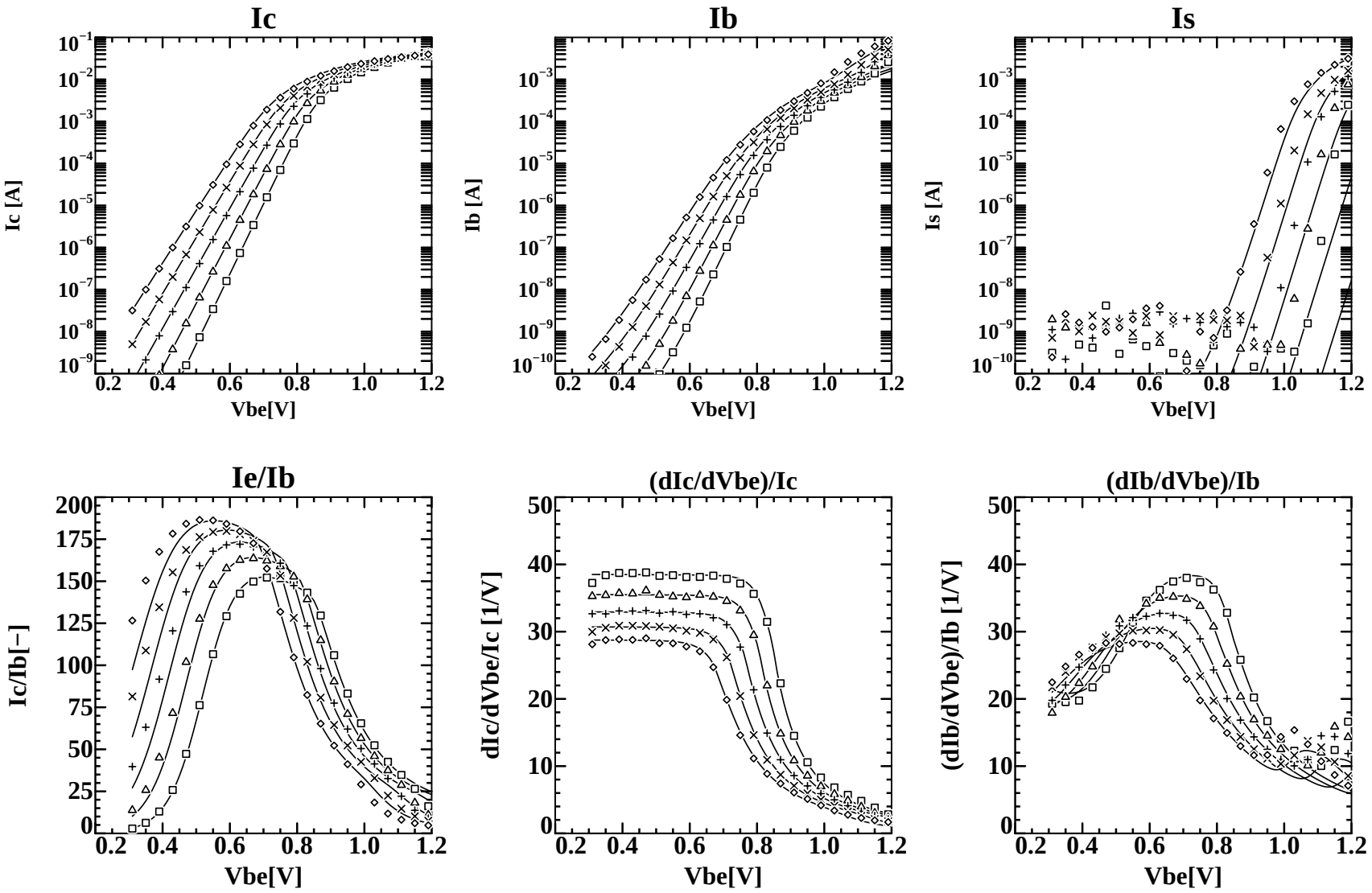
double base contact, $R_p = 10 k\Omega$

maximum cut off frequency f_T: 10 GHz at 5 Volt V_{ce}
(6 GHz at 500 mV V_{ce})

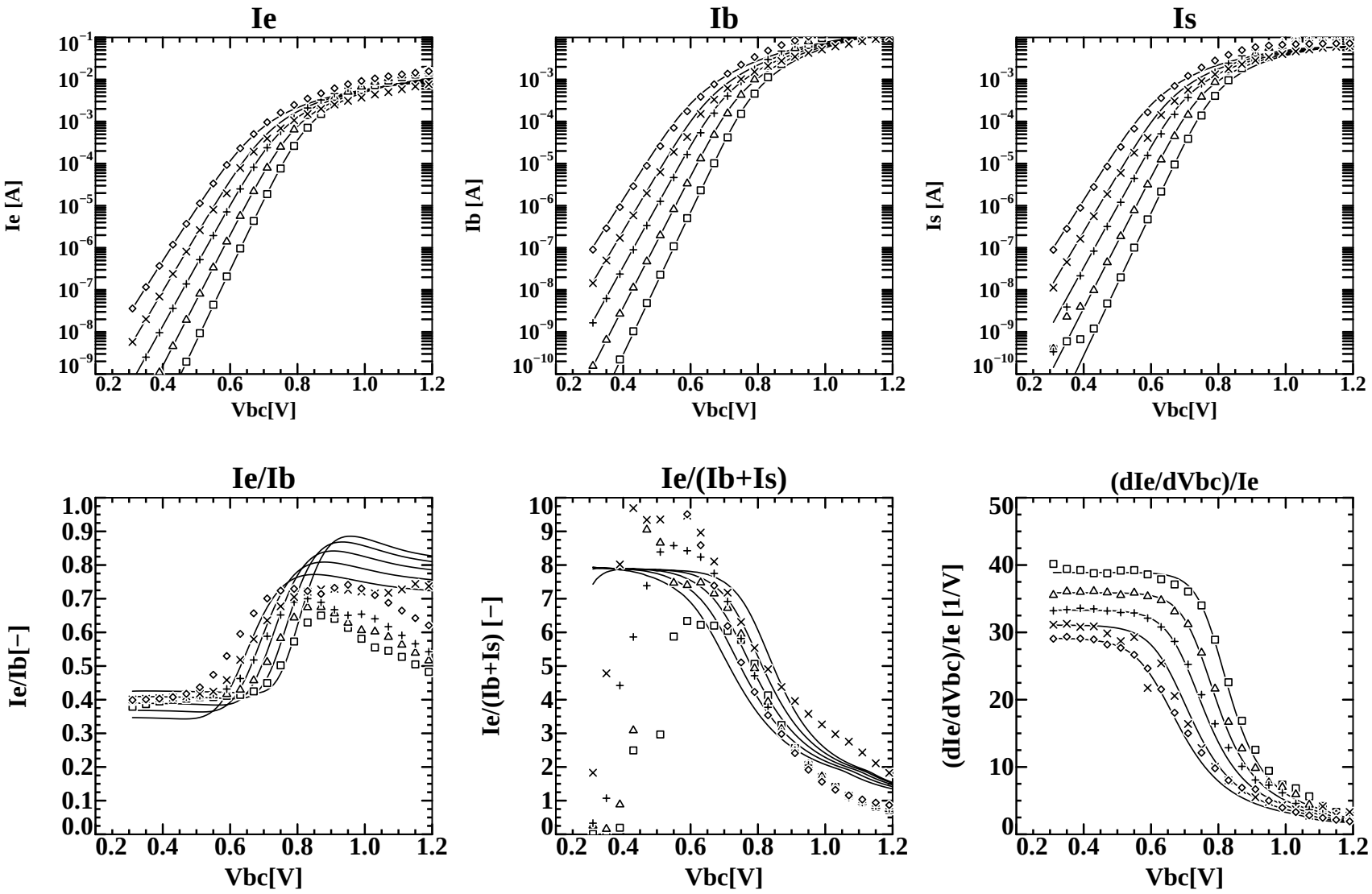
Process A: Cap Temp=25, 125 Mextram 503.2



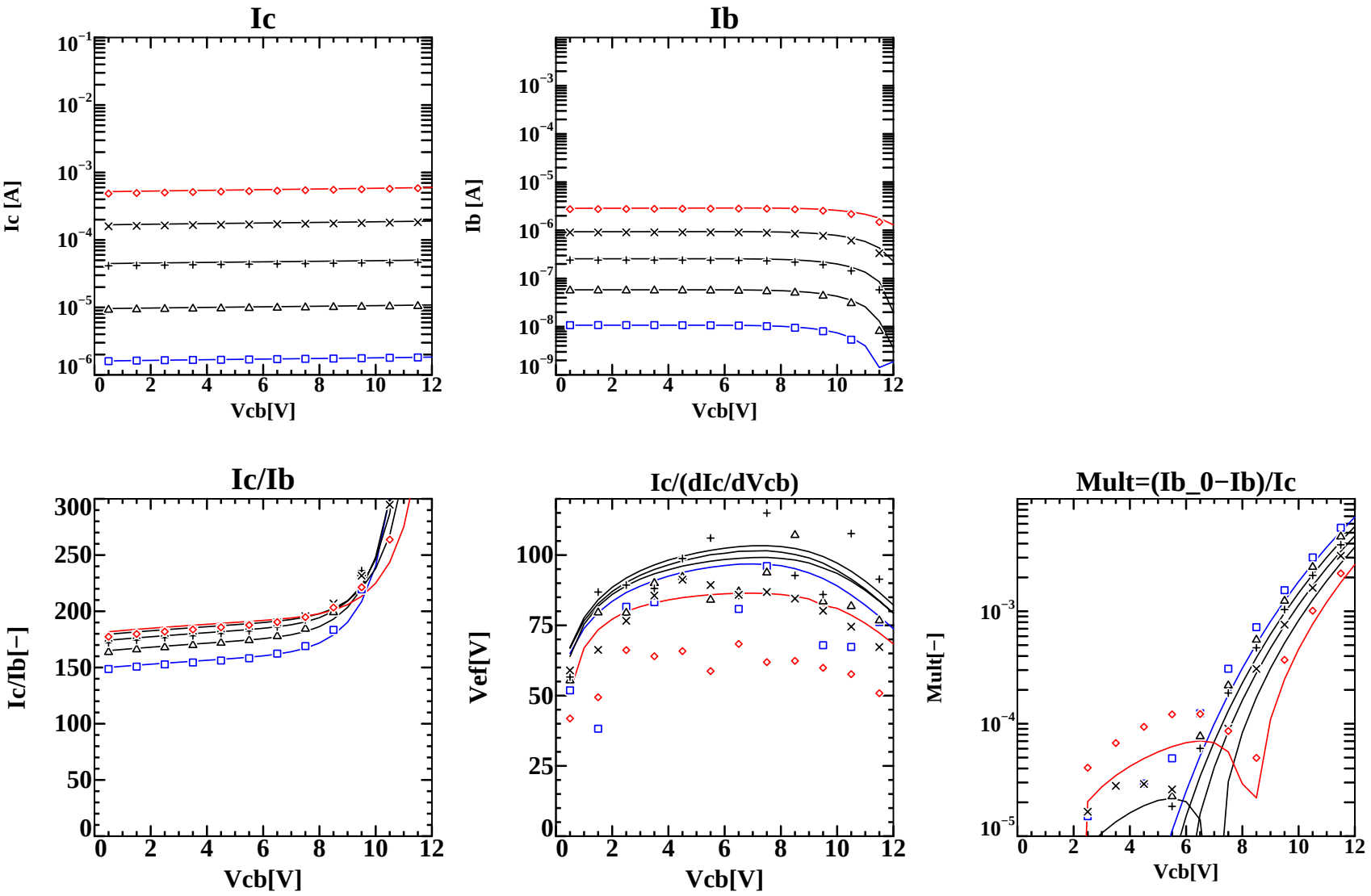
Process A: fgummel Vbc=0 Temp=25, 50, 75, 125, 150 Mextram 503.2 (7)



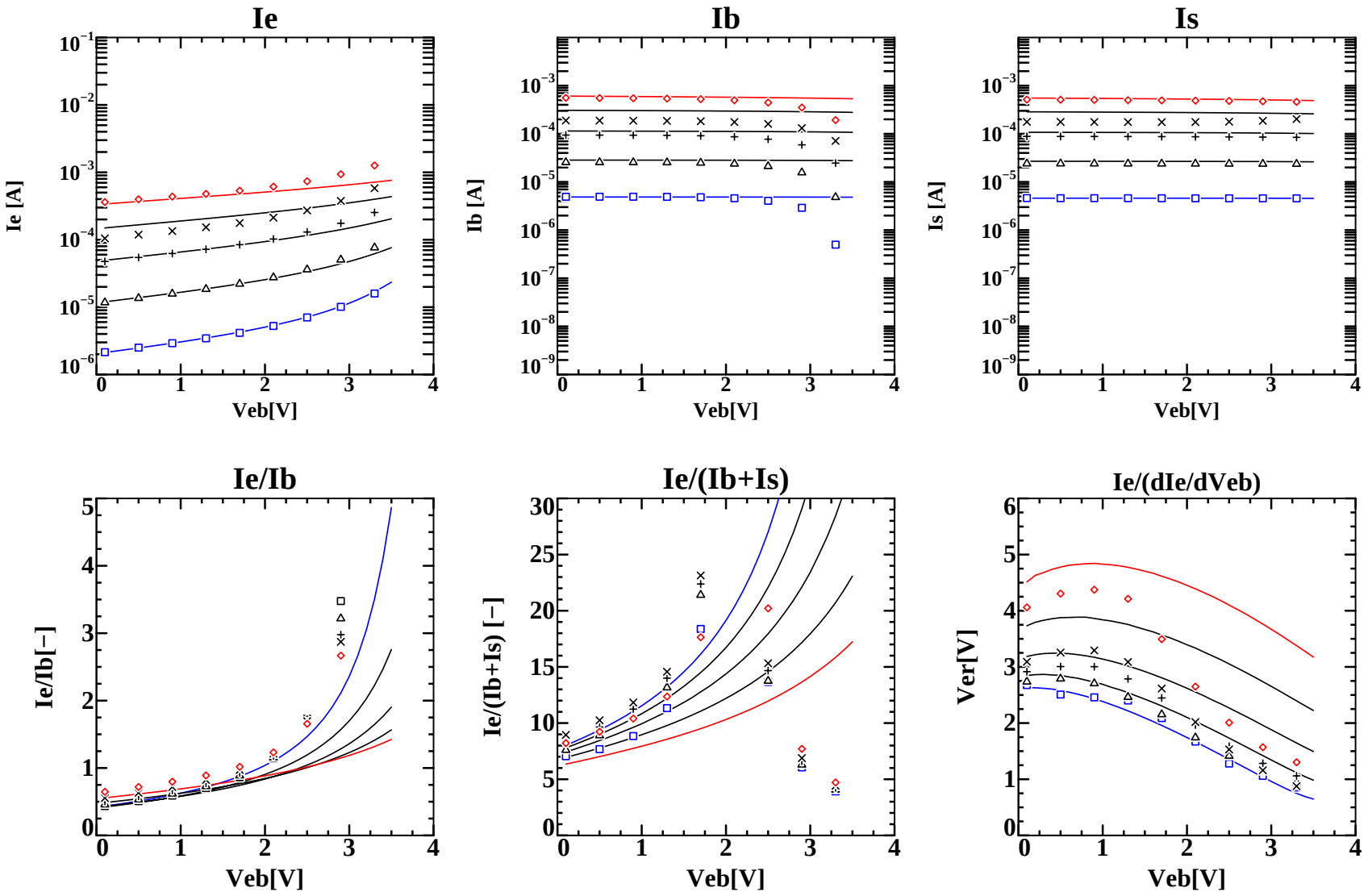
Process A: rgummel Vbe=0 Temp=25, 50, 75, 125, 150 Mextram 503.2 (8)



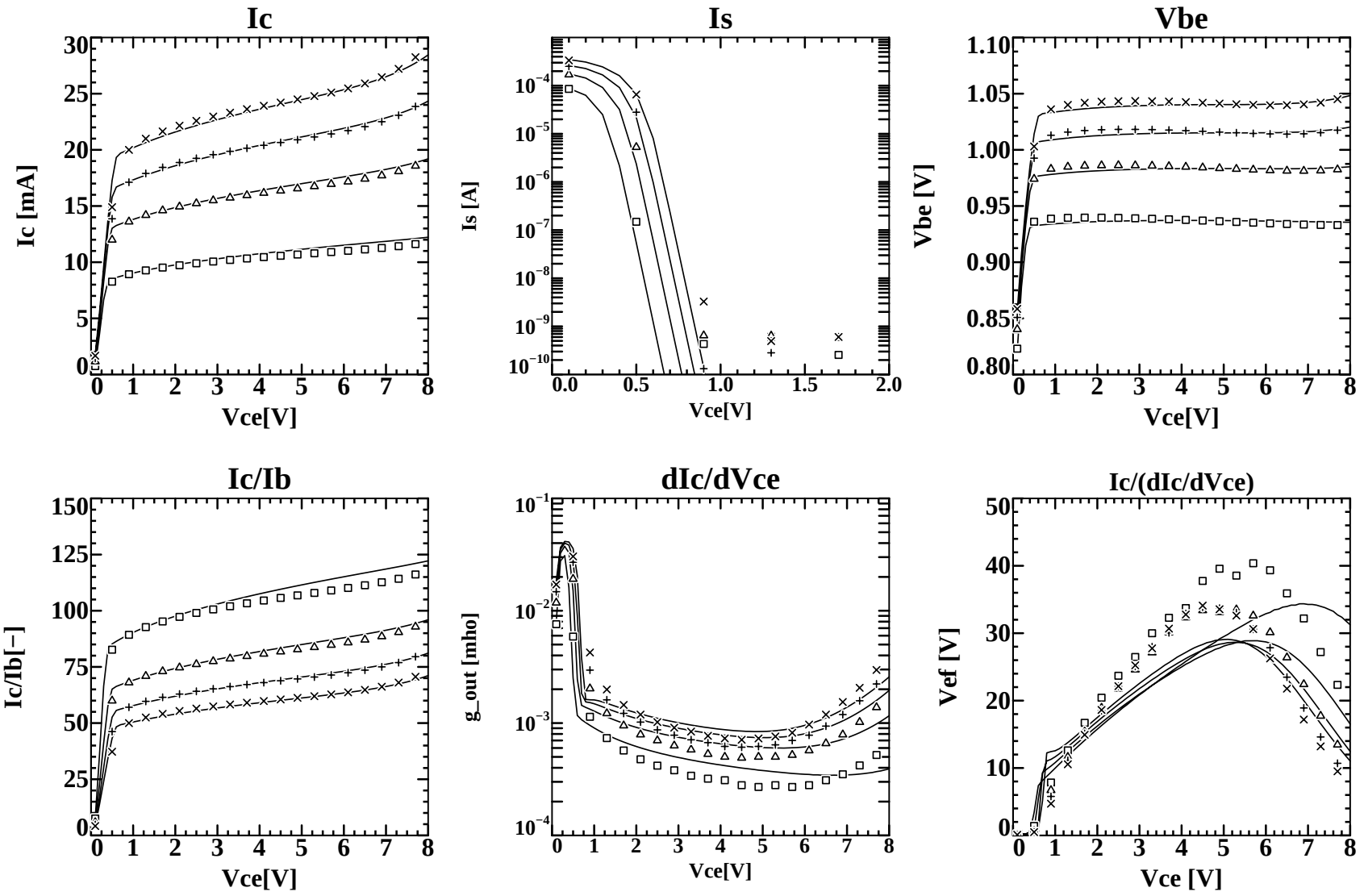
Process A: foutput-vbe Vbe=0.65 Temp=25, 50, 75, 125, 150 Mextram 503.2 (9)



Process A: foutput-vbc Vbc=0.65 Temp=25, 50, 75, 125, 150 Mextram 503.2 (10)



Process A: foutput-ib Temp=25 Ib=100, 200, 300, 400 uA Mextram 503.2 (11)



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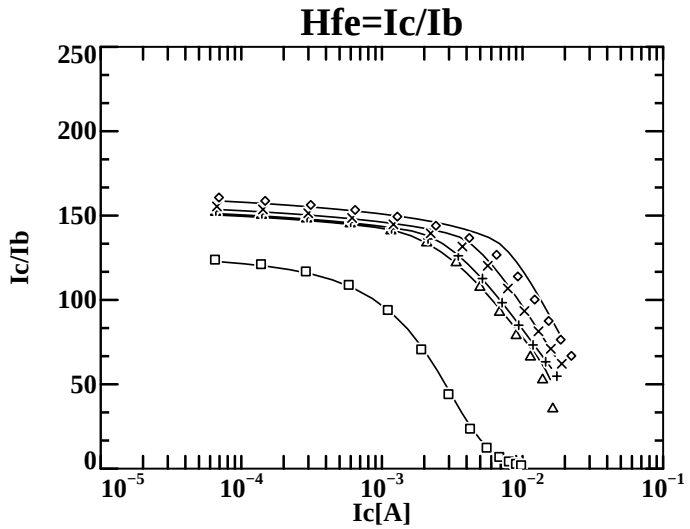
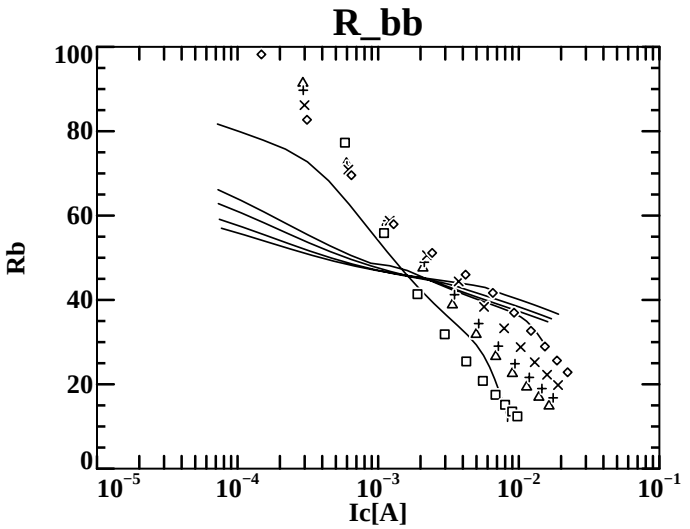
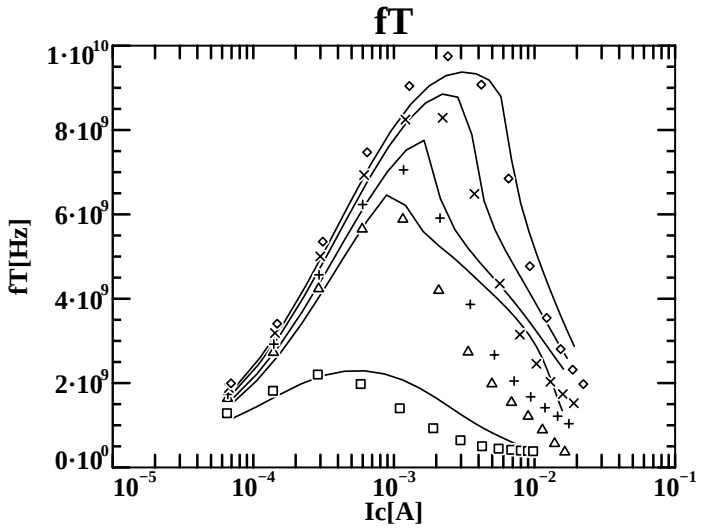
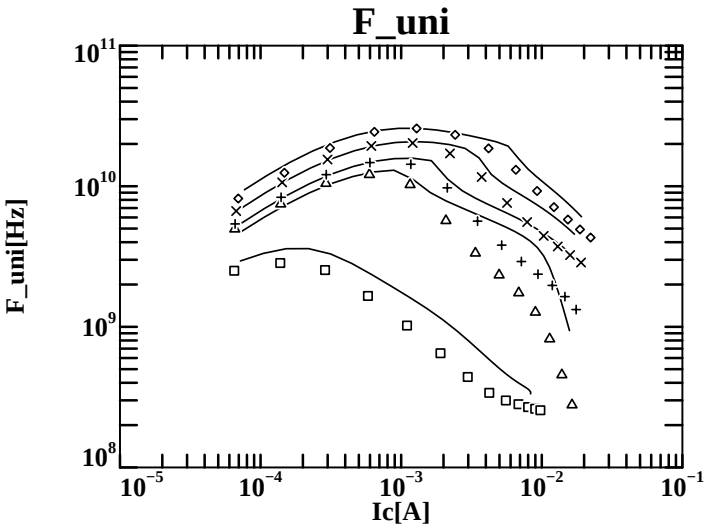
Process A: Temp=25 f=1 GHz, Vce=0.2, 0.5, 0.8, 2, 5 V Mextram 503.2 (12)









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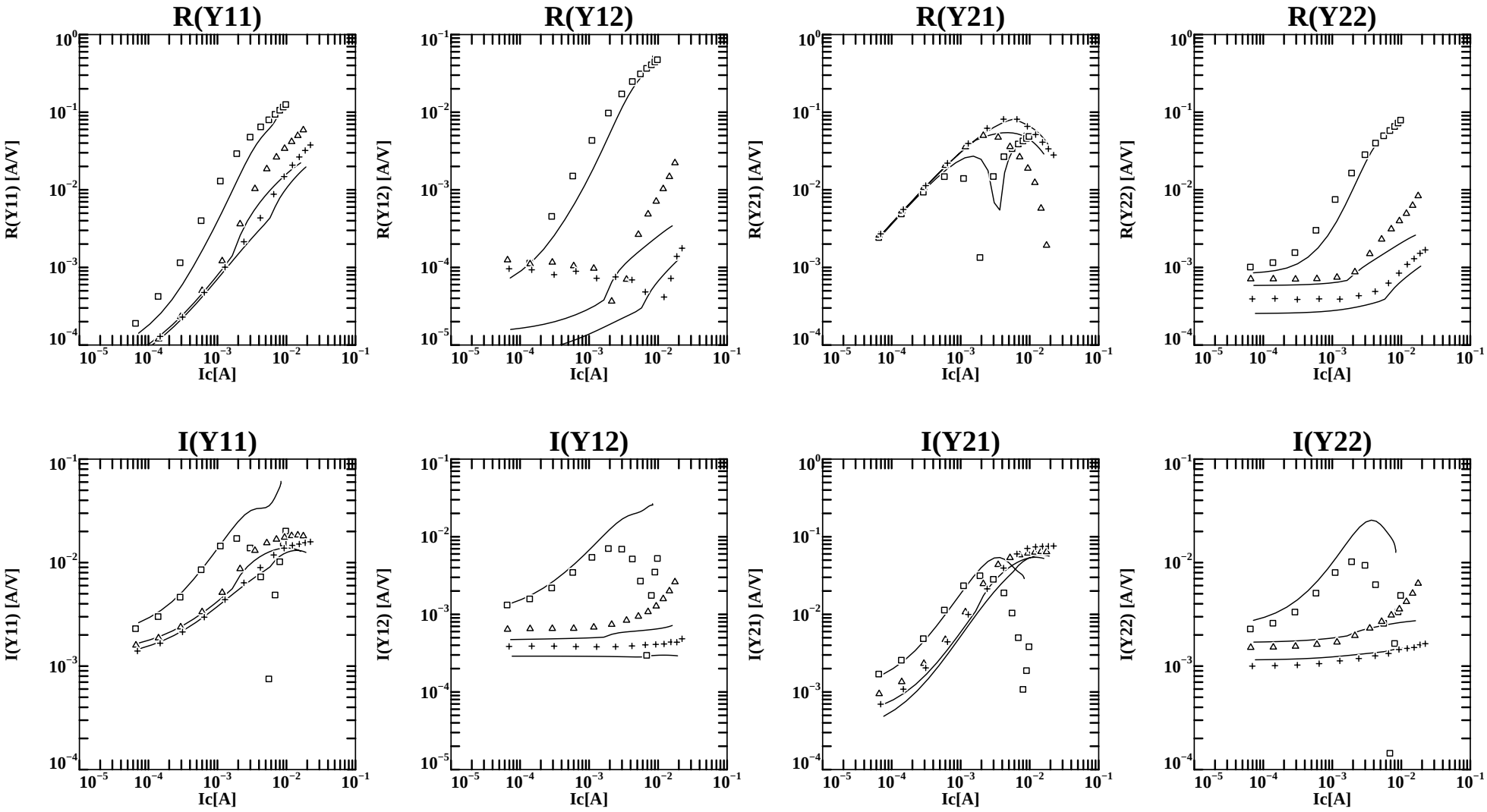
Process A: Temp=25 f=1GHz Vce= 0.2 □, 0.8 △, 5 + Mextram 503.2 (13)



Current and charge at onset of quasi-saturation: Mextram 504

Base widening starts when internal b-c junction becomes forward biased; i.e $V_{B_2C_2} = V_{d_c}$. We can calculate the current I_{ck} where this happens;

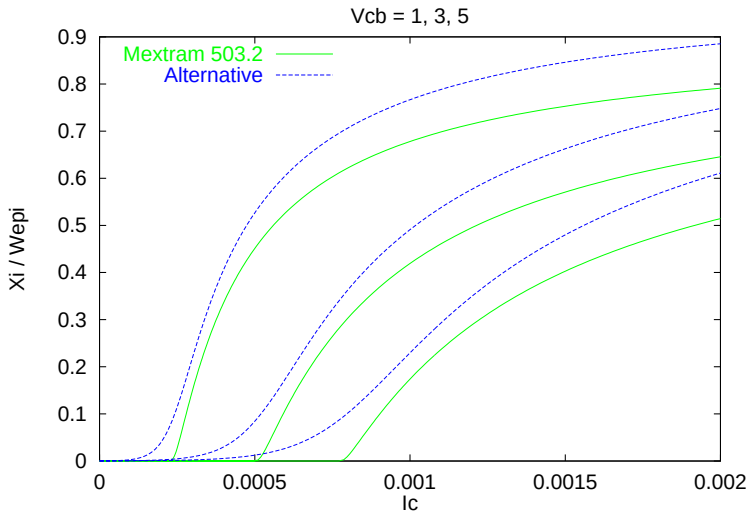
$$I_{ck} = \frac{\mathrm{V_{d_c}} - V_{B_2C_1}}{\mathrm{SCR_{C_v}}} \cdot \frac{\mathrm{V_{d_c}} - V_{B_2C_1} + \mathrm{I_{hc}} \cdot \mathrm{SCR_{C_v}}}{\mathrm{V_{d_c}} - V_{B_2C_1} + \mathrm{I_{hc}} \cdot \mathrm{R_{cv}}}$$

Now this current can be used to determine when Q_{bc} and Q_{epi} should start to increase. This then determines the position of the top of f_T.

possible solution:

$$Q_{bc} + Q_{epi} = \tau_{\mathrm{xi}} \cdot \left(\frac{x_i}{W_{epi}}\right)^2 \cdot I_c$$

$$\frac{x_i}{W_{epi}} = 1 - \frac{1}{1 + \mathrm{a_{xi}} \cdot \ln\left\{1 + \exp\left[\frac{I_c/I_{ck} - 1}{\mathrm{a_{xi}}}\right]\right\}}$$



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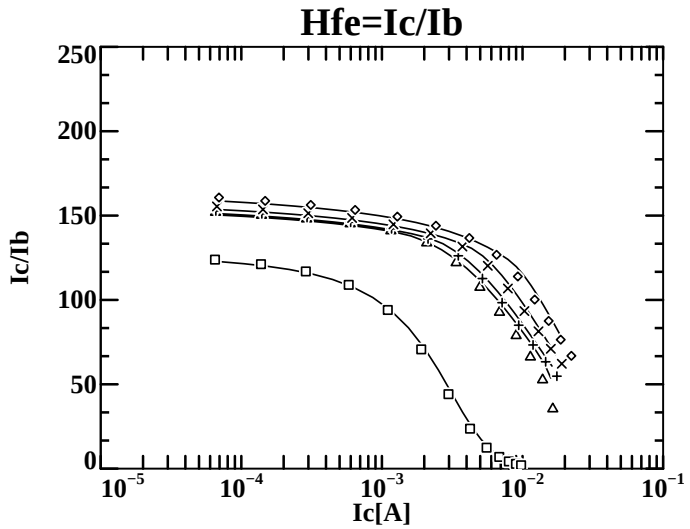
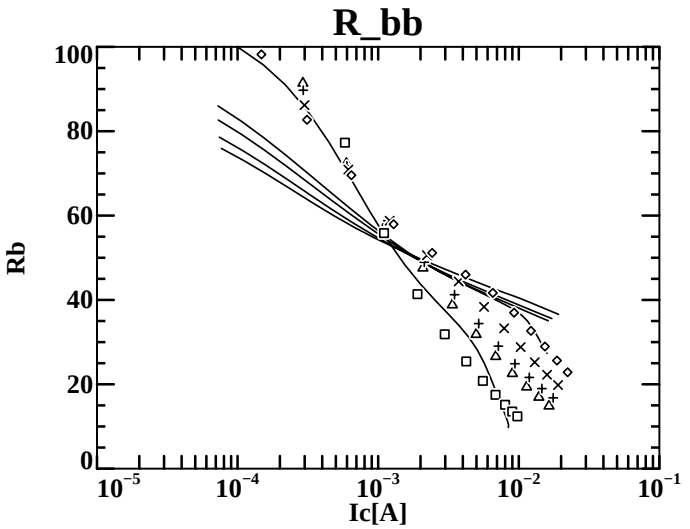
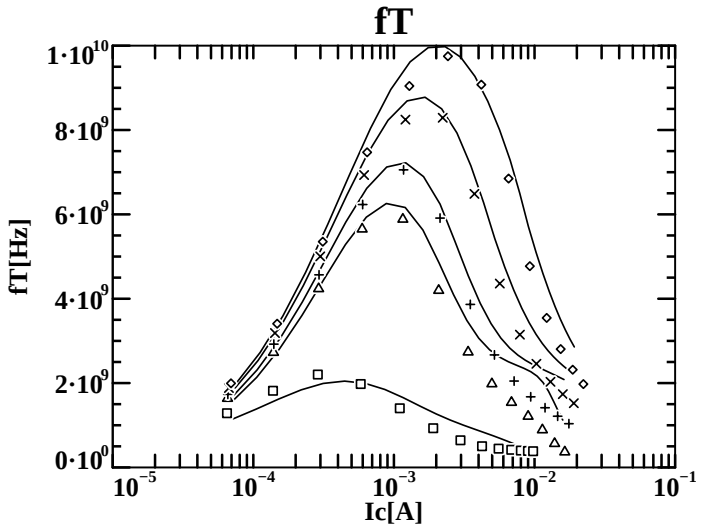
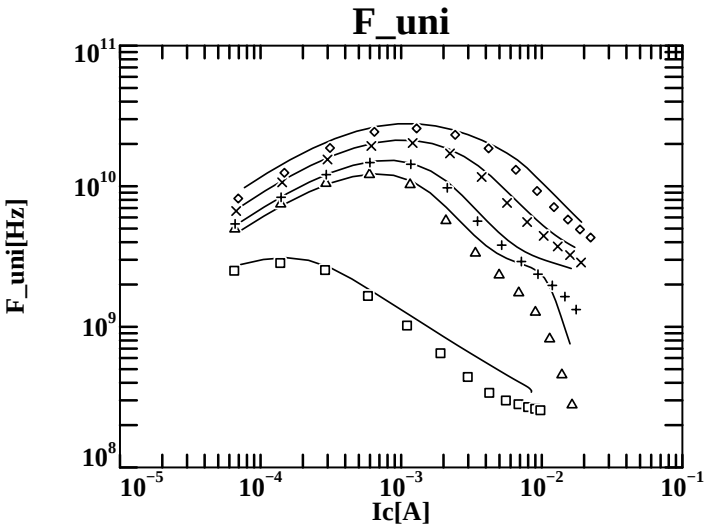
Process A: Temp=25 f=1 GHz, Vce=0.2, 0.5, 0.8, 2, 5 V Mextram 504.0 (15)









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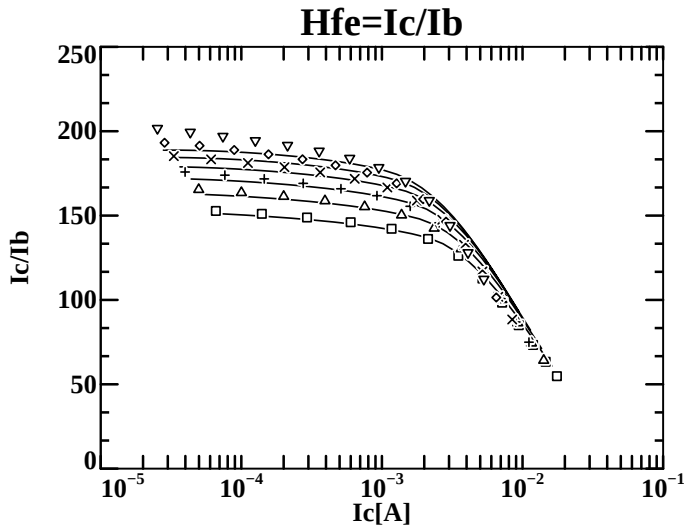
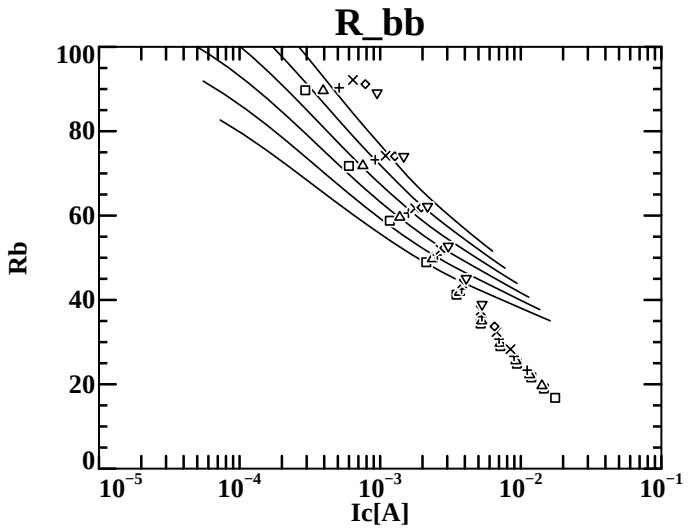
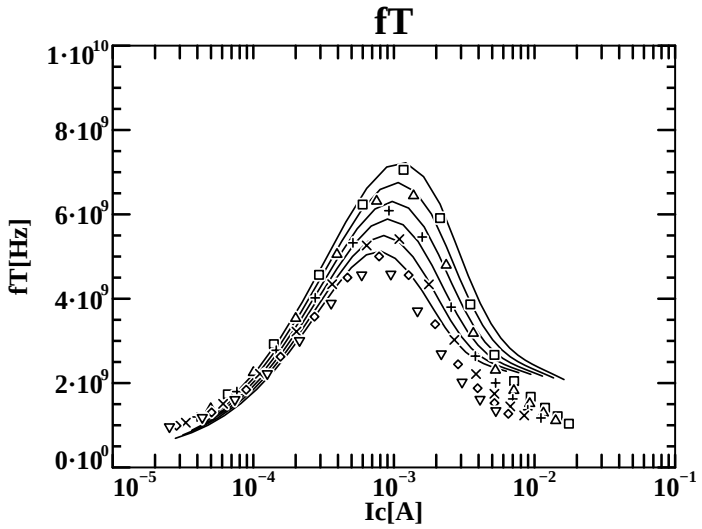
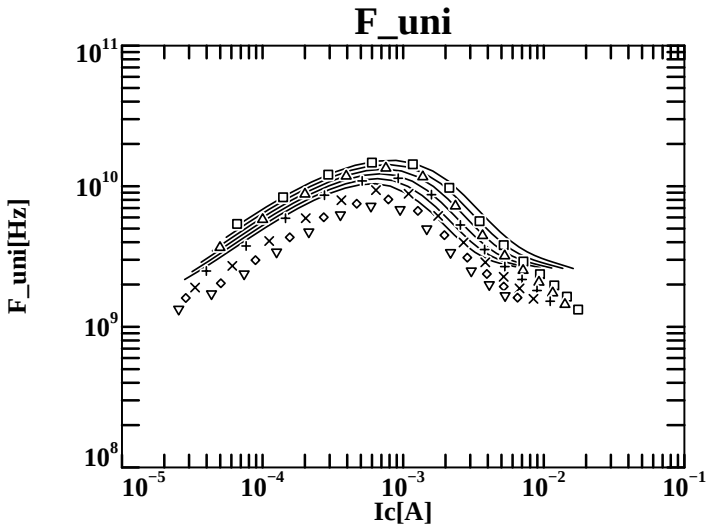
Process A: Vce=0.8 f=1 GHz, Temp=25 □, 50, 75, 125, 150 Mextram 504.0 (16)









Results: Process C

process C: NPN on SOI, no parasitic PNP $\rightarrow$ zero substrate current

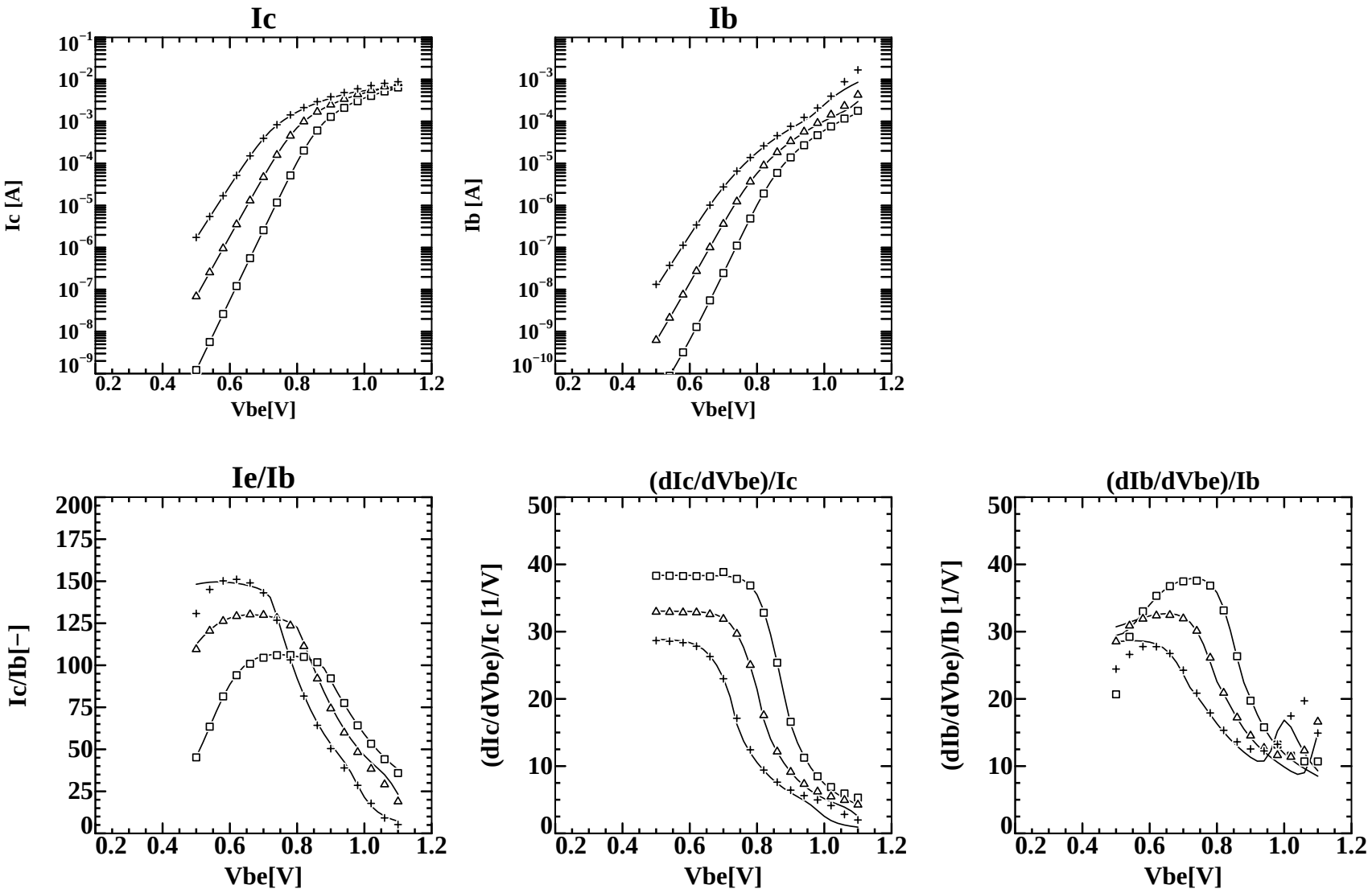
emitter size: $1.0 \times 5.\mu m$

double base contact, $R_p = 12k\Omega$

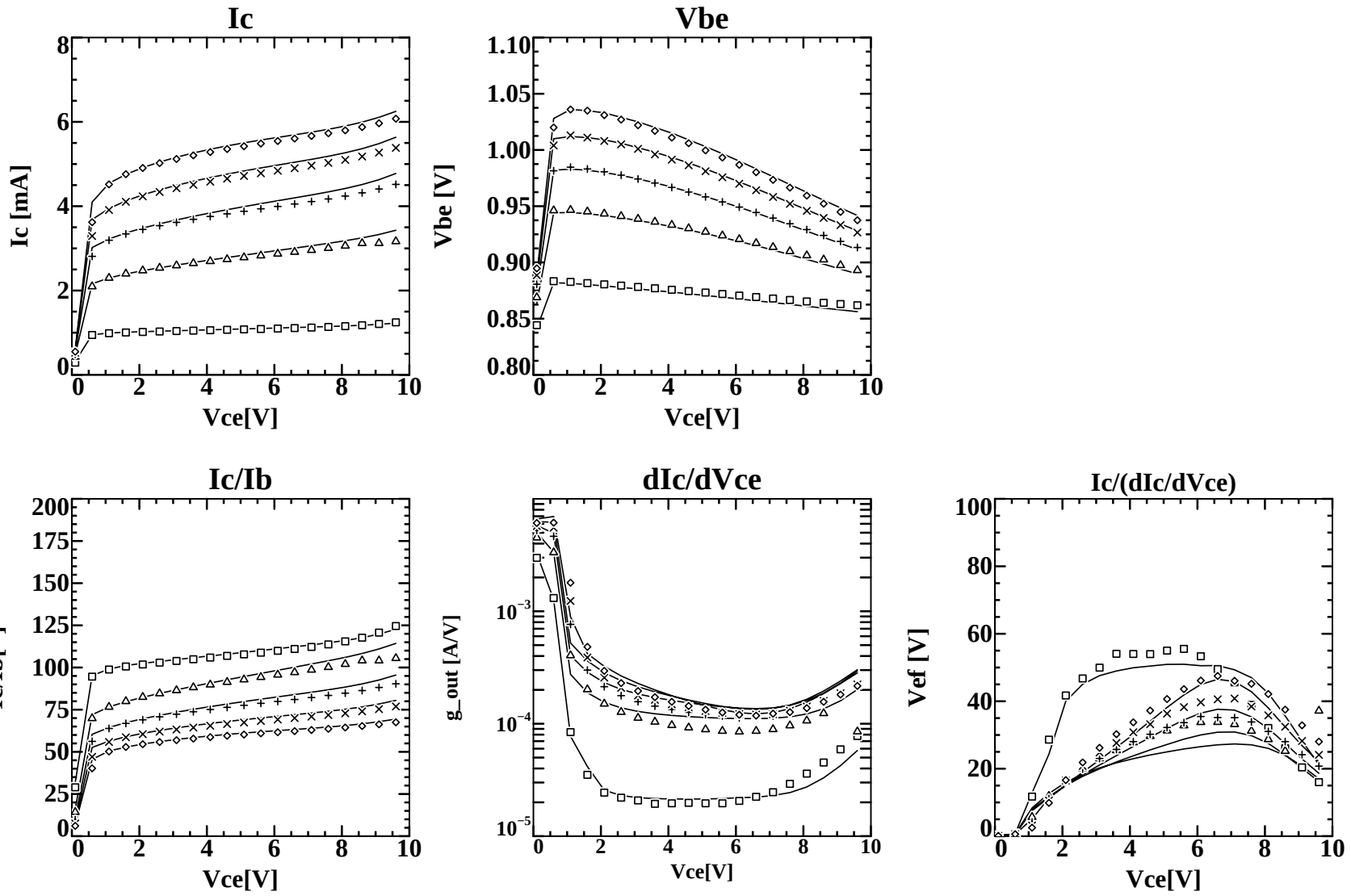
maximum cut off frequency f_T: 10 GHz at 6 Volt V_{ce}

large amount of self-heating: $R_{th} = 2500^oC/W$

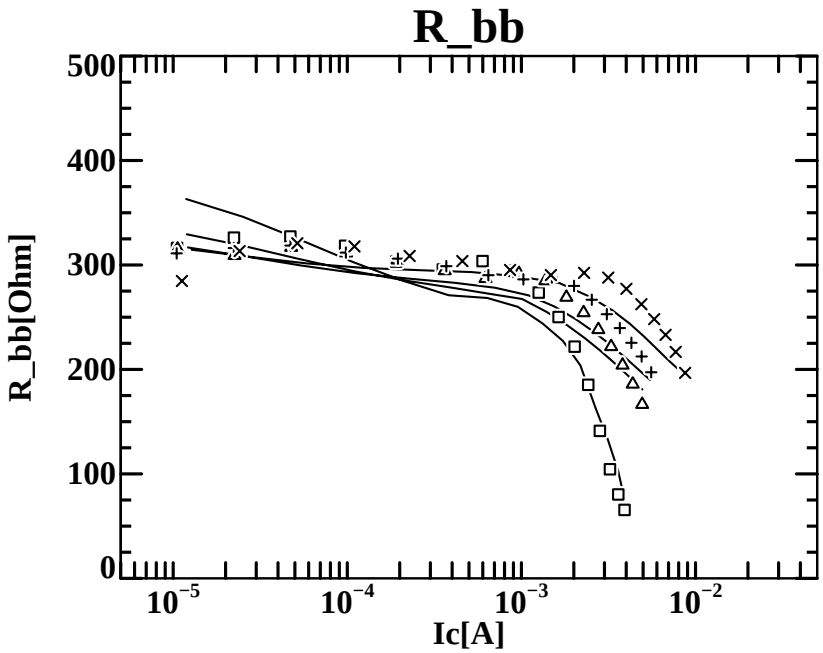
Process C: fgummel Vbc=0 Temp=27, 75, 125 Mextram 503.2

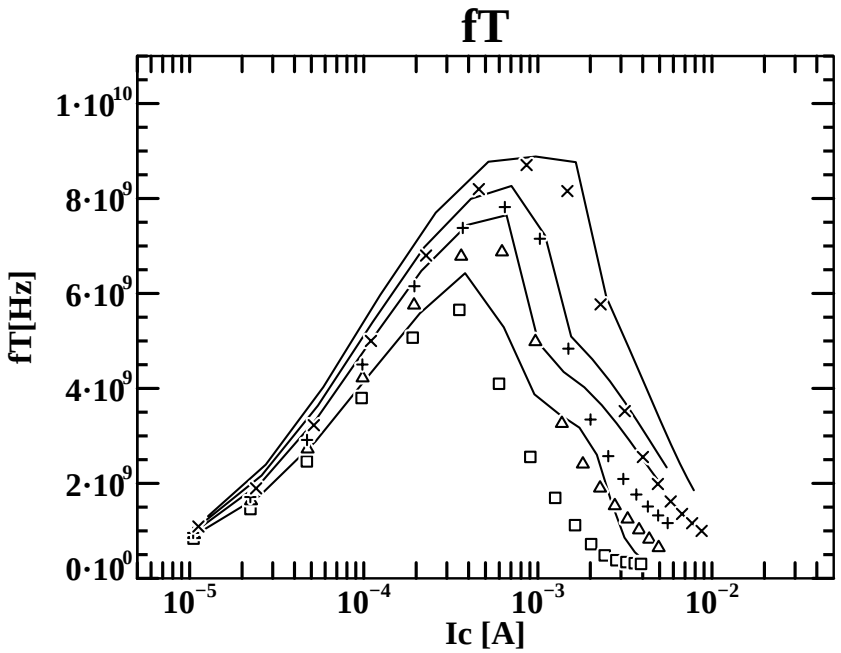


Process C: foutput-ib Temp=27 Ib=10, 30, 50, 70, 90 uA Mextram 503.2 (19)



Process C: Temp=27 f=993MHz Vce= 0.5 □, 1.0, 2.0, 6.0 Volt Mextram 503.2 (20)





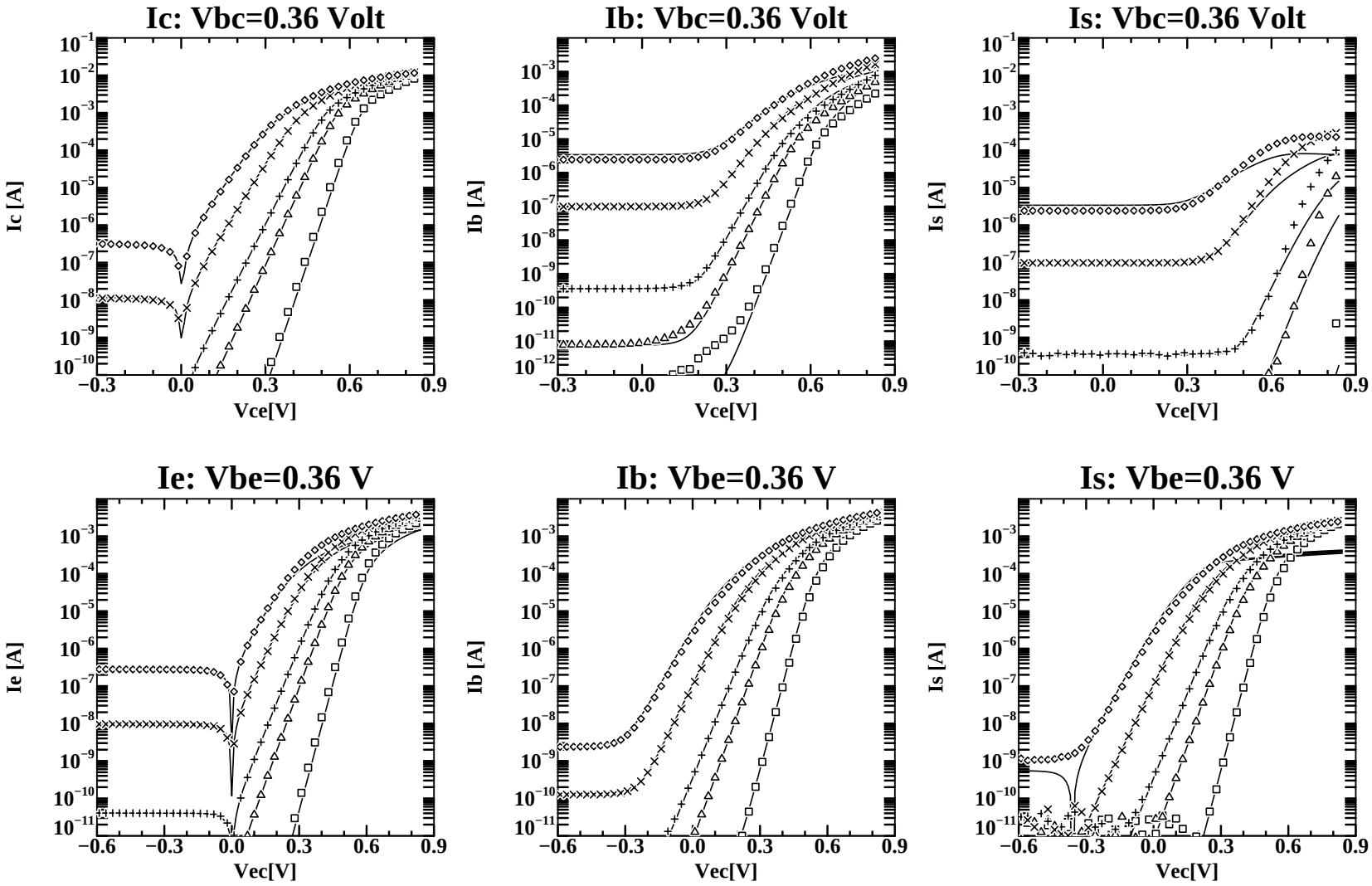
process D: NPN of a double poly BiCMOS process
with selective implanted collector (SIC)

emitter size: $0.55 \times 3.45 \mu m$

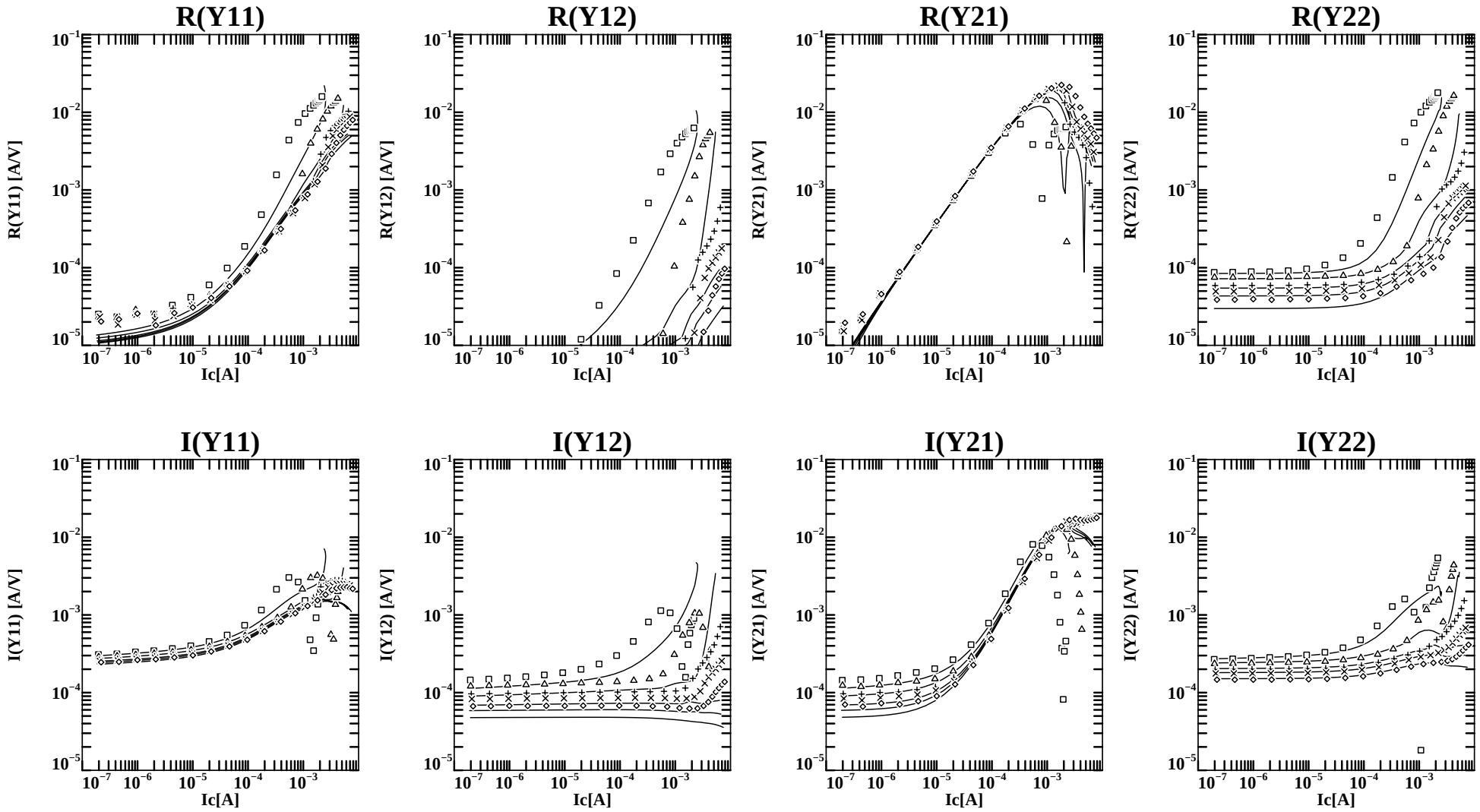
single base contact, $R_p = 9k\Omega$

f_T: 25 GHz at 1 Volt V_{ce}
F_{max} : 25 GHz at 0.9 Volt V_{ce}

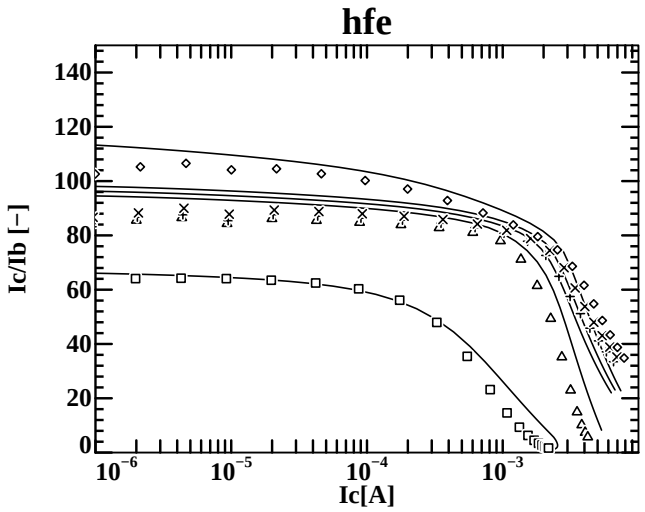
Process D: fgummel+rgummel Temp=-50, 25, 62.5, 137.5, 200 Mextram 503.2 (22)

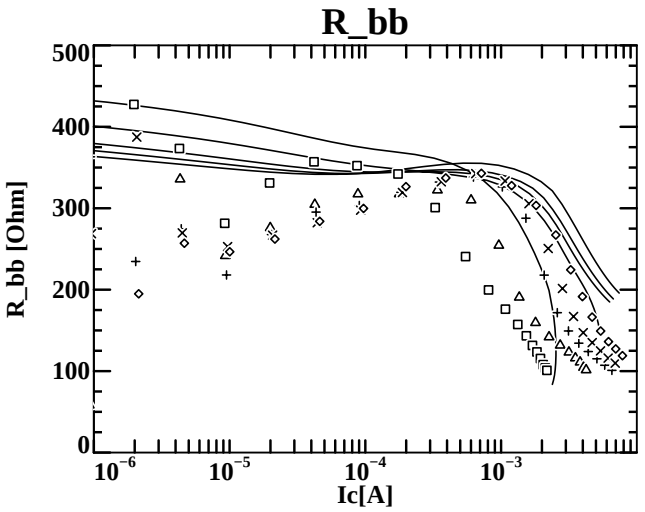


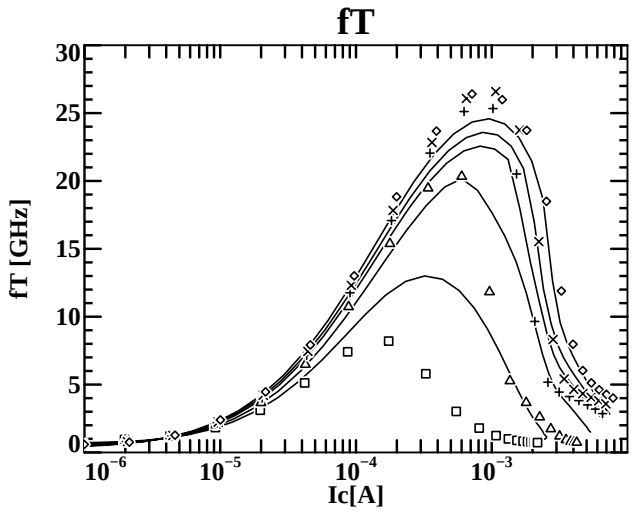
Process D: Temp=25, freq=1.8GHz, Vce=0.2, 0.4, 0.9, 1.5 Volt Mextram 503.2 (23)

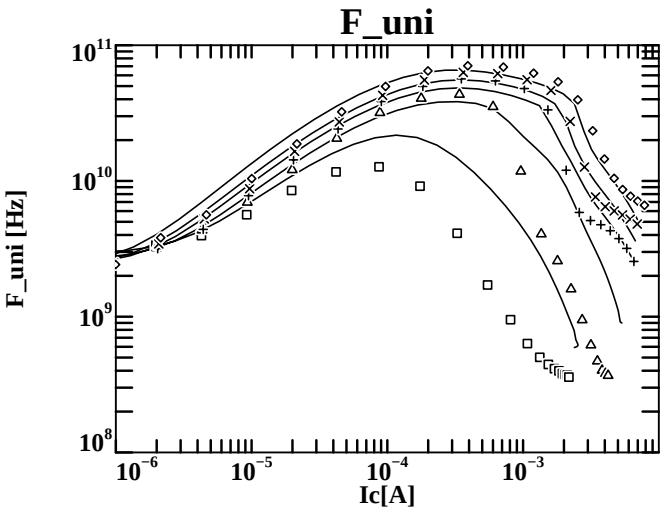


Process D: Temp=25, freq=1.8GHz, Vce=0.2, 0.4, 0.9, 1.5 Volt Mextram 503.2 (24)









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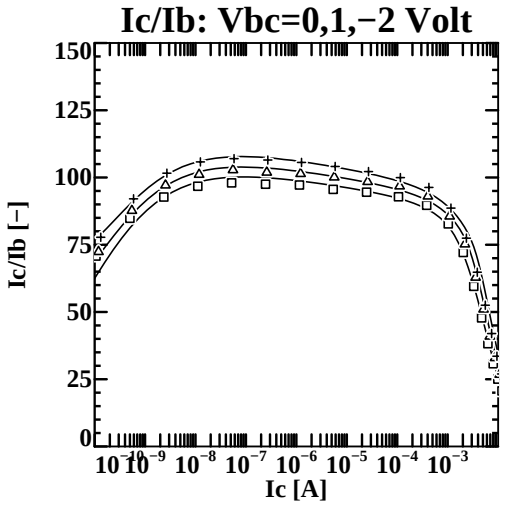
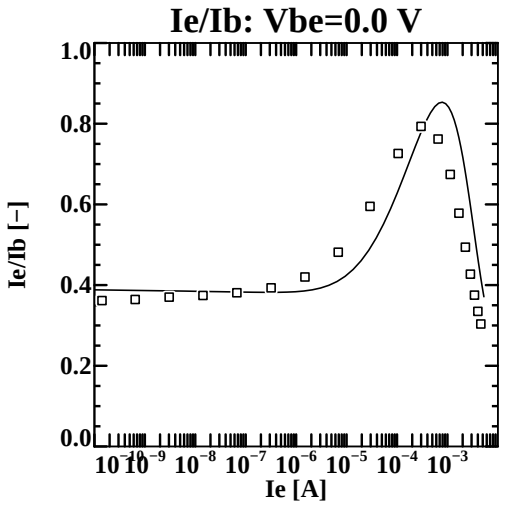
process E: NPN of a BiCMOS process

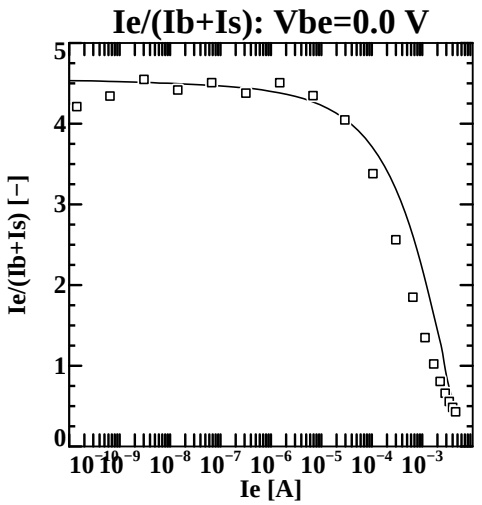
emitter size: $0.6 \times 4.8 \mu m$

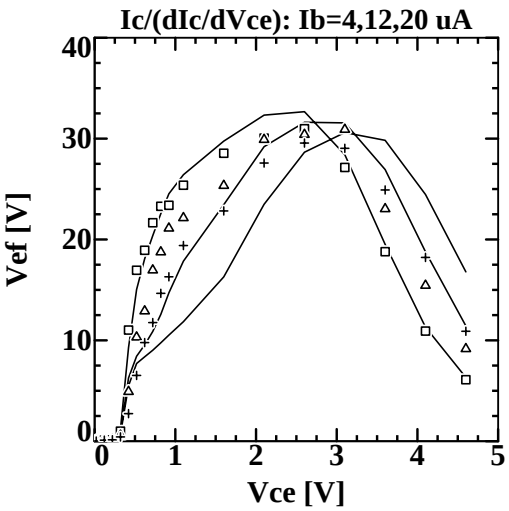
Sheet resestance base, $R_p \approx 10 k\Omega$

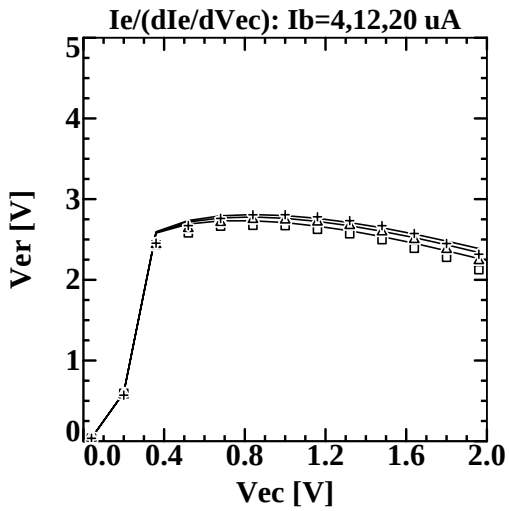
Process E: Mextram 503.2

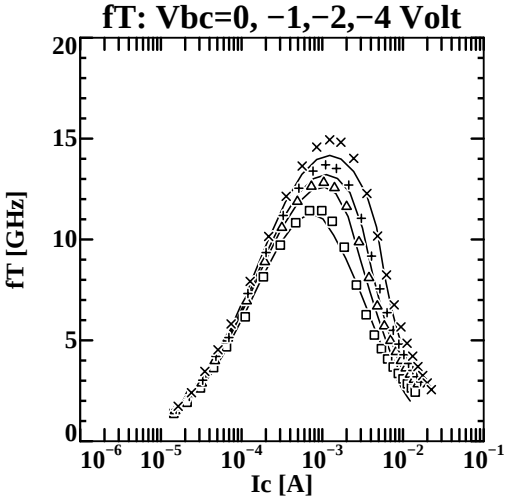












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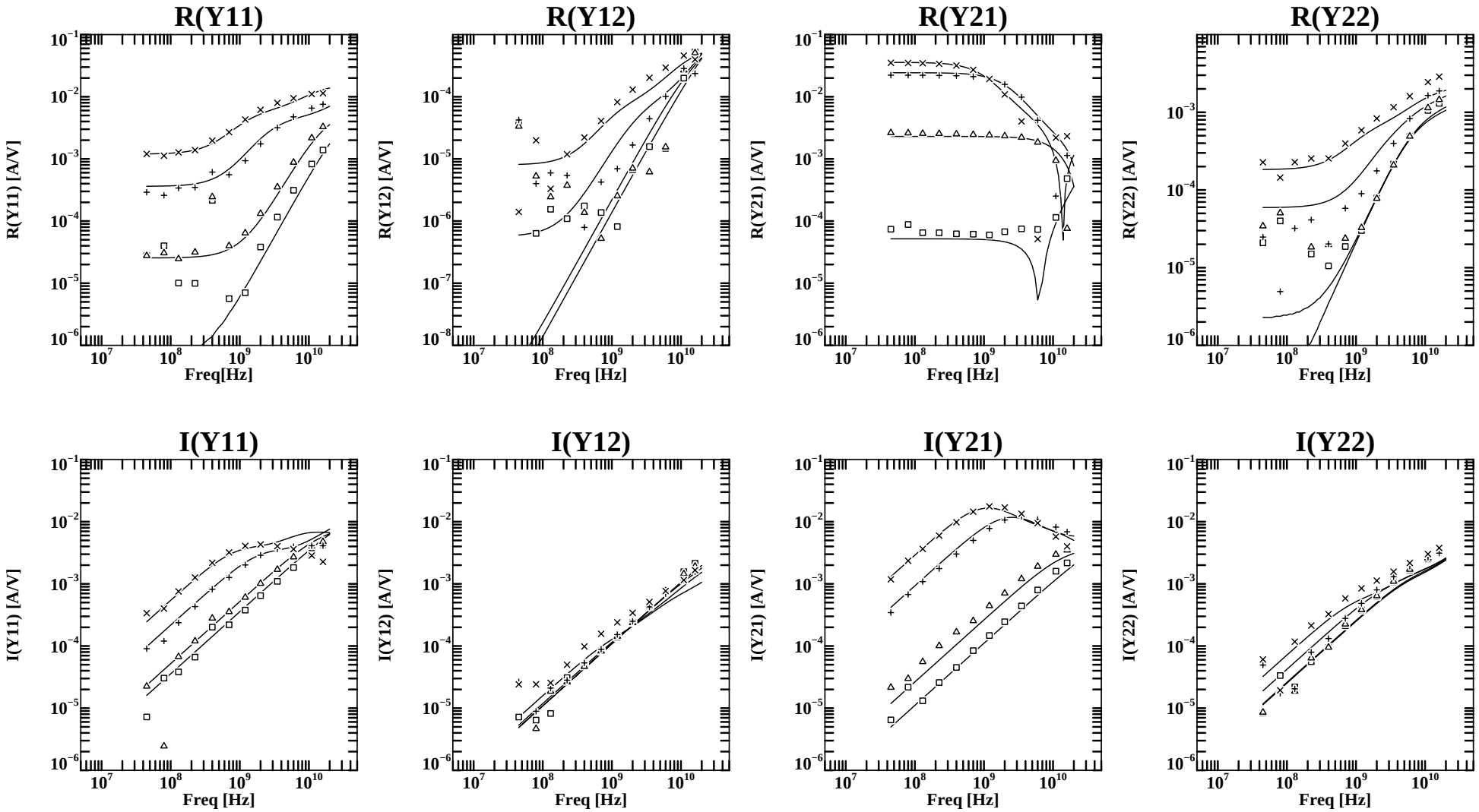
Process E: Vcb=0.0V, Vbe=0.7, 0.8, 0.9, 1.0 Volt Temp=21.4 Mextram 503.2 (27)



- We have characterized 5 of the 6 transistors
  - Mextram 503.2 parameter set
    + substrate resistance + self-heating parameters
  - simulated data for all measurements are provided
- Current data of process B (SiGe) can not be used for benchmarking
  DC and AC data are measured on different wafers in time.
  At least 2 parameter sets are needed
- Request to place simulated data + parameters of VIBIC, Hicum and Mextram on CMC web site in the same format and filenames as the measured data.
- Benchmarking of Mextram 504 will be done for the same data sets.